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Rapid automated processing of structural orientation from time-of-flight LiDAR mapping

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Abstract

The three-dimensional axis mapping (3DAM) method allows rapid capture and orientation of point cloud data to magnetic north in GPS and survey denied environments. From the collected point cloud data, the 3DAM algorithm automates the identification of rock structures and the processing of their orientation into a stereonet format, at the point of data collection, on a timescale measured in seconds. A tool, the Axis Mapper, was created based upon this method and is intended to streamline geological and geotechnical underground mapping of structural orientation data.

The objective of this paper is to compare the precision and speed of capture for the Axis Mapper's orientation measurement to the most prevalent method of orientation capture in underground mines, the structural compass.

Structural orientation data captured from two case studies—one, at a base metals mine in South America; the second, two mines in Ontario, Canada—were compiled and compared for precision and speed between the Axis Mapper's 3DAM method and a compass. Additional locations of data captured were planned but could not be collected for this paper. Sources of measurement interference, which could not be mitigated, were present at both case study locations.

The data collected from the case studies suggest that structural orientation captured by the Axis Mapper and compass are within 11° dip direction and 5° dip of each other; except in one discreet example which identified a dip difference of 23°. The Canadian case study suggests the Axis Mapper is up to three times faster at collecting structural orientation data when compared with the compass. The authors consider the conclusions preliminary and non-definitive due to the limited number of collection sites, limited available data, and uncontrolled sources of measurement interference. Additional data collected in controlled settings are necessary to better define the comparative precision and collection speed of the Axis Mapper data.

Keywords: *Axis Mapper, structural orientation, rock mapping, geotechnical mapping, stereonet*

1 Introduction

The collection of geotechnical and geological mapping data in underground mines is important for tasks such as controlling grade, verifying mine design parameters, and optimising the geometry of mine workings. Observations of mapping practices in underground mines suggest there are several access and time constraints associated with collecting sufficient mapping data. Mines under time or access restraints sometimes forego collection of sufficient mapping data and instead introduce higher uncertainty and, consequently, more conservative designs or resource estimates. Faster mapping can generate data which would not otherwise be captured and subsequently decrease uncertainty for several operational and design assessments.

An important component of mapping data is the orientation of structures, both for structural stability and geological assessments. The current methods of orientation collection involve manual hand measurements or the capture of large quantities of geospatial point cloud data for post-processing in one of several available software suites. Typical methods include compass measurements, visual estimates, and LiDAR or photogrammetry spatial data capture. Each method has unique benefits and detriments which will not be discussed as part of this paper.

A new method, three-dimensional axis mapping (3DAM), which utilises short-range LiDAR and automatically processes structural orientation at the point of measurement, has been developed and published previously (Gallant & Marshall 2016). A tool called the Axis Mapper utilises 3DAM to address the identified need for faster data collection methods underground. The purpose of this study is to determine what precision and speed benefits the Axis Mapper offers underground mapping operations when compared to the most commonly utilised method for orientation data capture, the structural compass. Data captured to support this paper was limited in location and quantity due to restrictions placed on movement and site access in the wake of the COVID-19 pandemic.

The orientation data available for comparison as part of this study was collected from a base metals mine in South America and from two mines in Ontario, Canada. The data sets were examined to draw conclusions on the precision and speed of structural orientation measurements using the Axis Mapper compared with measurements obtained using the structural compass. This paper discusses the construction and use of the Axis Mapper tool, the methodology chosen for data collection and comparison, the interpretation, and the conclusions drawn.

2 Axis Mapper design

The Axis Mapper, shown in Figure 1, is a handheld data collection tool used for geotechnical mapping in underground environments. The four main aspects of the Axis Mapper include the physical hardware, the software, the 3DAM method, and related algorithms. The intended use for the Axis Mapper is for underground environments where geotechnical assessments are performed. The Axis Mapper was designed to be used by a single individual and prioritised ease and speed of use, portability, and durability.

Figure 1 Axis Mapper design (rendered version)

2.1 Hardware

The Axis Mapper is 30 cm (L) × 33 cm (W) × 15.1 cm (H) in size, weighs 4.9 kg, and does not require the setup of a monopod or tripod. The two main instruments contained within the Axis Mapper are a time-of-flight LiDAR (ToF) sensor and an inertial measurement unit (IMU). The ToF sensor is a short-range LiDAR which has a maximum scanning distance of 5 m and performs optimally in environments without infrared interference from sunlight. The IMU contains an accelerometer, gyroscope and magnetometer which measures the orientation of the Axis Mapper.

Additional hardware includes a colour video recorder capturing photos of measured surfaces and displaying live video during the capturing process, a flashlight to illuminate the scan area for the video feed, a touch screen and stylus for user interaction when recording observed data supplemental to structural orientation (i.e. RMR, Q', characterisation, etc.), an ergonomic harness to mitigate physical stress during extended use, and a charger for the rechargeable battery.

2.2 Software

The software which provides measurement capture and processing is on-board the device. The software includes a patented algorithm which performs structural orientation mapping, known as 3DAM (Gallant & Marshall 2016), to process dip and dip direction measurements on-board the device within seconds. The software also contains workflows specific to rock mass characterisation focussed on face mapping and scanline mapping.

2.2.1 3DAM algorithm

The 3DAM algorithm combines the ToF and IMU sensor measurements to derive structural orientation measurements within seconds. When the device is pointing at a feature, the ToF sensor data generates normal vectors of the feature from the perspective of the device. At the same time, the IMU data estimates an orientation path of the device. The normal vectors are transformed to the device orientation to generate dip and dip direction values. The 3DAM algorithm incorporates additional filters to identify and remove outliers due to surface irregularities. The method is discussed in detail in other publications (Gallant & Marshall 2016) and is outside the scope of this paper.

2.2.2 Rock mass characterisation

The Axis Mapper incorporates rock mass characterisation, outside of orientation data capture, as electronically fillable workflows. These workflows include face mapping and scanline mapping as standard. This supplemental data collection is not the subject of assessment or comparison in this paper.

2.2.3 Data export and format

Data is exported from the Axis Mapper by means of Wi-Fi or USB. The data output of the Axis Mapper includes automatically generated Excel files of dip and dip direction measurements and supplemental rock mass characterisation information, stereonet graphs, and colour images.

2.3 Use of the Axis Mapper for structural orientation measurements

The use of the Axis Mapper for structural orientation measurements is similar to photo capture using a digital camera and requires calibration of the IMU.

2.3.1 Axis Mapper calibration

The Axis Mapper must be calibrated to a specific geographic location to sync the earth's expected magnetic field with the measured magnetic field. The calibration only needs to be performed once per mine or project location. For this study, the Axis Mapper was calibrated as recommended for each measurement location.

2.3.2 Structural orientation data collection

The mapping screen on the device provides a depth image overlain with the video feed which shows the Axis Mapper's field of view. The Axis Mapper also provides real-time feedback on the strength of the magnetic field (Mag Norm) in the bottom right corner, a live-readout of a stereonet at the top left corner, the strike of the drift orientation in the top left corner, and the distance between the Axis Mapper and the targeted rock face in the bottom left corner, shown in Figure 2.

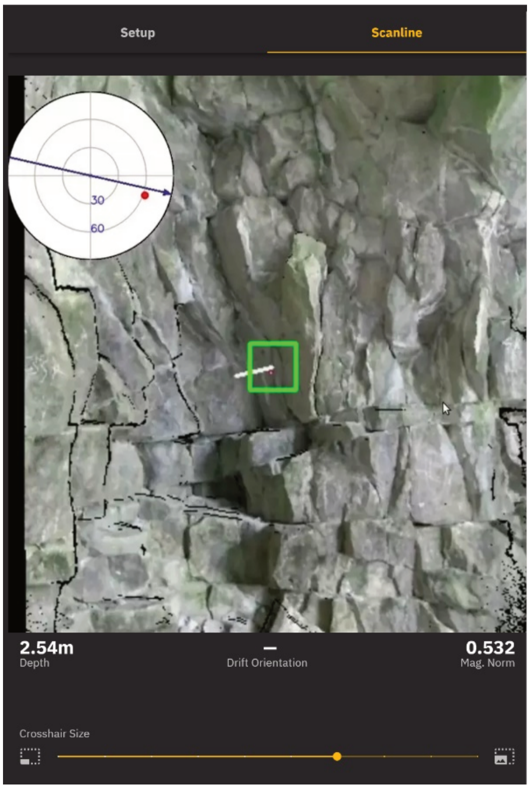


Figure 2 Mapping screen on the Axis Mapper

To capture structural orientation measurements, a user holds the device with their two hands and points it at a feature of interest up to 5 m away. The feature of interest must be within the green box (crosshair) in the centre of the screen. If the crosshair is green, there are enough data points for the 3DAM algorithm to process. If the crosshair is red, there are enough not enough data points for the 3DAM algorithm to process and the user must adjust the Axis Mapper until the crosshair turns green. The size of the crosshair can be adjusted to allow capture of single or multiple structures simultaneously. Under ideal circumstances, the minimum size of a structure that can be captured at the maximum distance of 5 m is 20 × 20 cm.

A user then presses a physical button to initiate orientation measurement capture over a period of 3 seconds. The 3DAM and associated algorithms then process the structural orientation. The orientation is presented in a stereonet and as a numerical average dip and dip direction measurement. An image of the structure, captured from the scanning screen, is also recorded and presented.

2.3.3 Magnetic field feedback

When collecting data, the magnetometer continuously measures the magnetic field surrounding the Axis Mapper and reports the value to the user as a Mag Norm. The Axis Mapper can generate accurate measurements when the magnetic field (Mag Norm) is within 0.1 Gauss of the measured or expected earth's magnetic field specific to the measurement location.

3 Data collection methodology

To achieve this paper's objective, data was collected across three different sites using a repeatable approach to minimise variables which could invalidate the results or obscure meaningful correlation. The data collected was limited in scope to structural orientation and time spent collecting data. A direct measurement by measurement comparison was made between the Axis Mapper and a compass at all three sites to assess measurement precision. The three sites were split into two case studies, based upon geography.

Case study 1 was conducted at a South American site, at which data was collected by RockMass Technologies Inc. (RockMass) staff and local mining company staff. This site was selected based on a pre-existing agreement for data capture allowing RockMass staff continuous access to underground environments. Additionally, this site contained extensive historical geotechnical mapping data that was collected using a structural compass on a near-daily basis. This site was selected prior to the COVID-19 pandemic. Additional data collection and comprehensive comparison with historic data was planned, however, due to the COVID-19 pandemic, site access was severely affected resulting in limited data being captured for the purpose of this study.

Case study 2 was conducted at two Canadian sites (Site A and Site B), at which data was collected by RockMass staff. Considering the COVID-19 travel and access restrictions, these two locations were locally accessible for additional data capture to further supplement the data unable to be collected in South America. The locations available for RockMass staff locally were not ideal testing environments due to significant sources of interference (detailed below), however, other locations for data capture were not available at the time of this study.

Additional location access was discussed with third parties but had been delayed due to government or company specific travel and access restrictions.

3.1 Collected data

The data collected and compared for this paper is focussed on orientation measurements of individual structures using both the Axis Mapper and a structural compass in an effort to better define the capability of the Axis Mapper compared to traditional methods. A structural compass was chosen for comparison as it is the most prevalent method of orientation estimation used underground. Other studies will need to examine comparisons to alternative methods of orientation data capture.

Timed data collection was only captured for case study 2 due to the limited scope of case study 1. This timed data collection was captured with the intention of drawing a conclusion on the comparative data collection speed of the Axis Mapper.

3.2 Measurement locations

The two case studies involved collecting individual structural measurements along a single heading for each site. Structures were chosen ahead of time and measurements using both the Axis Mapper and a compass were performed on the chosen structures. The South American measurement location was within an inactive drift in a dolomitic rock type and both Canadian measurement locations were within newly developed portals within 100 m of surface in greywacke or gneiss rock types.

3.3 Measurement procedure

The measurement procedure for the case studies focussed on comparative assessments between a compass and the Axis Mapper. As the compass is an accepted tool for capturing orientation data in underground environments, the deviation between data captured from a compass and the Axis Mapper will help to identify the comparative precision of the Axis Mapper.

3.3.1 Case study 1: South American site's individual data precision procedure

Case study 1 was conducted within a good quality and massive dolomitic rock mass.

Six structures were identified for measurement. Three compass measurements were collected for each feature to account for small variability on the structure due to measurement error or rough and uneven surface conditions.

Measurements using the Axis Mapper were collected at each structural feature at an approximate distance of 2 m. A total of four measurements were taken from different angles; looking straight at the feature, from left of the feature, from right of the feature, and from below the feature. These angles did not exceed 30° from a vector perpendicular to the feature.

Additional data capture was planned at the South American site but was unable to be completed due to access restrictions stemming from COVID-19 precautions.

3.3.1.1 Case study 1 interference

A concern during data collection was that sources of interference would impact measurement accuracy and result in inconclusive results. Sources of interference could include, but are not limited to, magnetic interference (impacting the Axis Mapper and compass), physical access to structures (interfering with the compass), or wet surfaces (interfering with the Axis Mapper).

The data capture environment for case study 1 contained no significant rock support or magnetic interference near the chosen structures for both the structural compass and 3DAM approach. In some circumstances, the structural compass was unable to contact the chosen structure to ensure an appropriate standoff distance.

3.3.2 Case study 2: Canadian sites' data precision and timing procedure

The two mines, Site A and Site B, contained hard rock lithologies with similar structural characteristics. As such, the data capture methodology for the Canadian mines were identical.

A total of 108 structures were identified for measurement across both sites, with 50 of those measurements captured at Site A and 58 captured at Site B. At both sites, most structures were located within 100 m of the portal entrance along a 20 to 30 m length of the ramp wall. Site B included some structures measured at a surface outcrop near the portal. Structures were measured in a single row. The identified structures were chosen to be no more than 2 m above the ramp floor, such that access was possible using a compass.

The intent of the capture method was to provide similar levels of access for both data capture methods with the intent that the only variable in the study was the choice of data collection method.

The identified structures were then marked with a white spray-painted dot approximately 5 cm in diameter to delineate the location of measurement. The Axis Mapper crosshair encompassed the entire dot within the measurement crosshair resulting in a single orientation measurement, while the compass collected a single measurement per structure at the centre of the dot, an example of which is shown in Figure 3.

Figure 3 Example structure at Site A with spray-painted dot showing location of measurement

A single user collected the measurements using the Axis Mapper and compass; the Axis Mapper was utilised first on all structures and was then immediately followed by compass measurements. A separate technician recorded time spent by the user collecting both sets of measurements and recorded the orientations provided by the user when measuring with the compass (this was done to limit any delay during data capture with a compass).

Time comparisons examined in this article only examine speed related to orientation measurement capture and do not consider any possible time savings during data transfer from the Axis Mapper, transcription of written compass data to digital media, or post-processing or compass measurements. The measurements were then transferred to a spreadsheet for comparative analysis to assess the precision of each individual measurement and the time spent collecting each set of measurements.

3.3.2.1 Case study 2 interference

For the Canadian case study, efforts were made to control experimental parameters, however, due to scheduling and access issues encountered by the research team, some sources of interference were encountered and affected the study data. The sources of interference and their potential effect are listed below:

- Sources of compass interference:
  - Ground control (fully bonded rebar bolts with face-plates and welded wire mesh with 10 cm spacing):
    - Ground control prevented contact between the compass and some identified structures.
    - Proximity to metal ground control interfered with the compass strike measurement for some structures.
  - Magnetic rock types, some structures were located within or near secondary lithologies which contained magnetic materials:
    - Magnetic interference altered dip direction readings from the compass when close to some identified structures.
- Sources of 3DAM interference:
  - Wet surfaces from groundwater inflow at Site B underground:
    - Structures which were either coated in condensation or running water which refracted the infrared light emitted by the ToF sensor reducing the speed of Axis Mapper data capture for some structures.
  - The magnetic rock types did not affect the Axis Mapper measurement because the Axis Mapper was able to collect data at a distance sufficiently far from the rock mass to avoid the altered magnetic field.
  - Infra-red radiation emitted from the sun:
    - During data collection at the Site B outcrop, sunlight may have affected the LiDAR infrared sensor with erroneous data. Steps were taken to mitigate this possibility by scanning within shadows, however, some interference may have still been experienced.

Twenty-five of the 58 structural measurements collected at Site B are from structures on a rock outcrop near the portal entrance. These 25 measurements were conducted to avoid interference from the magnetic rock, ground support, and wet surfaces, however, it also introduced potential LiDAR interference from sunlight.

4 Data interpretation

The comparison will be assessed separately for the Canadian and the South American case studies due to the differences in data collection procedure. A summary of the collected data available for comparison is presented in Table 1.

Table 1 Summary of measurement data for comparison assessment

Location	Number of structures measured	Measurement method	Start date of measurements	End date of measurements
Case Study 1, South America	6	Axis Mapper and compass	18 July 2019	18 July 2019
Case Study 2, Site A, Canada	50	Axis Mapper and compass	19 August 2020	19 August 2020
Case Study 2, Site B, Canada	58	Axis Mapper and compass	25 August 2020	26 August 2020

4.1 Measurement precision

Measurement precision is compared for individual structures across both case studies. The program Dips (Rocscience Inc. 2020) was utilised for visualising the precision comparison. The data was also captured in a worksheet for which the difference in dip and dip direction between the methods were identified for each individual structure. This data was summarised and examined for statistical differences.

4.1.1 Case study 1: South American mine site individual structural data

The multiple measurements collected from each structure using both data collection methods were averaged per method and structure ID for this comparison.

Table 2 provides a summary of the readings and their differences. Figure 4 displays this data stereographically.

Table 2 Precision comparison between six individual structures

Structure ID	Compass dip measurement (°)	Compass dip direction measurement (°)	Difference in average Axis Mapper dip measurement (°)	Difference in average Axis Mapper dip direction measurement (°)
1	60.0	143.3	1.2	-5.3
2	75.0	328.0	0.2	-1.0
3	35.3	285.3	21.4	-5.1
4	68.3	267.6	-1.4	0.6
5	50.0	234.3	3.2	-0.1
6	51.6	243.0	-0.3	-4.8

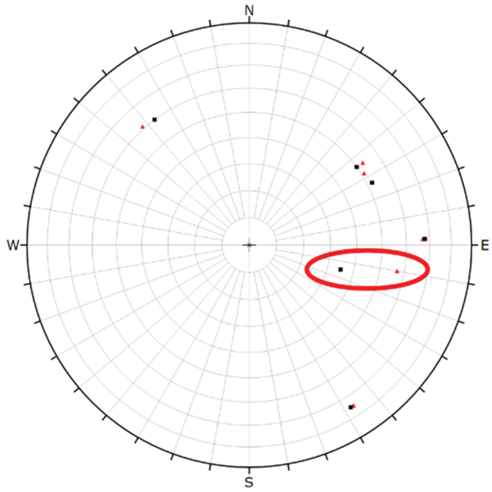


Figure 4 Stereographic display of compass (black square) and Axis Mapper (red triangle) measurements for individual structure measurements

The dip data taken with the Axis Mapper are all within 3° of the compass measurements with the exception of one feature. For structure ID 3, four measurements were taken using the Axis Mapper which produced results within 17–23° in variation of the compass measurement consistently. The cause of this error may be due to difficulty accessing the structure with the compass or user error of either the Axis Mapper or compass.

The dip direction measurements taken with the Axis Mapper were all within 5° of the compass measurements. Sources of error which may account for the variation in dip direction measurements are the waviness of the joint sets measured and the compass measurements which were taken at a distance or above an engineer's head for structures with poor access.

The stereographic display shows a similarity in dip and dip direction measurements using both approaches, excluding minor variance, for all structures except for the one circled in red in Figure 4. This structure was noted to have a highly variable measured dip between both methods. This case study shows a correlation between the two approaches, however, because a limited sample size of six features were recorded, the correlation should not be considered definitive.

4.1.2 Case study 2: Canadian mine sites individual structural data

Three data sets were collected from different locations during the Canadian study. 50 measurements were collected at Site A, 25 measurements were collected from a surface outcrop at Site B, and 33 measurements were collected underground at Site B.

Table 3 provides a precision comparison between the two methods at each of the three locations and indicates how many compass measurements were suspected of having interference. Average differences between the Axis Mapper and compass measurements recorded for each individual structure are presented in Table 3.

Table 3 Precision comparison between individual structures at three locations

Location	Axis Mapper angular difference in dip (°)	Axis Mapper angular difference in dip direction (°)	Number of poles	Compass measurements affected by interference
Site A	4.0	17.0	50	16
Site B outcrop	3.7	10.7	25	–
Site B underground	4.4	11.0	33	12

Table 4 provides a precision comparison between the two methods at each of the three locations after structures, for which compass measurements are suspected of error due to magnetic interference or structure obstruction, as discussed in Section 3.3.2.1, were removed.

Table 4 Precision comparison with structures suspected of measurement error removed

Location	Axis Mapper angular difference in dip (°)	Axis Mapper angular difference in dip direction (°)	Number of poles
Site A	4.4	9.6	34
Site B outcrop	3.7	10.7	25
Site B underground	4.2	9.2	20

The comparison data suggests the Axis Mapper is, on average, within 4° of dip and 11° of dip direction measurements. The correlation is not definitive and may have been affected by sources of interference which were not readily identified by the research team, however, the scans completed at the Site B outcrop, with no interference, correlate well with the remaining modified data sets in Table 4.

Data was previously captured using the 3DAM method and published in a previous paper (Gallant & Marshall 2016). While this data is not new, it serves as a useful check for consistency with the limited data set utilised in this study. The data captured during 3DAM development is shown in Table 5 and suggests a precision difference between 3DAM and a structural compass of up to 13.7°.

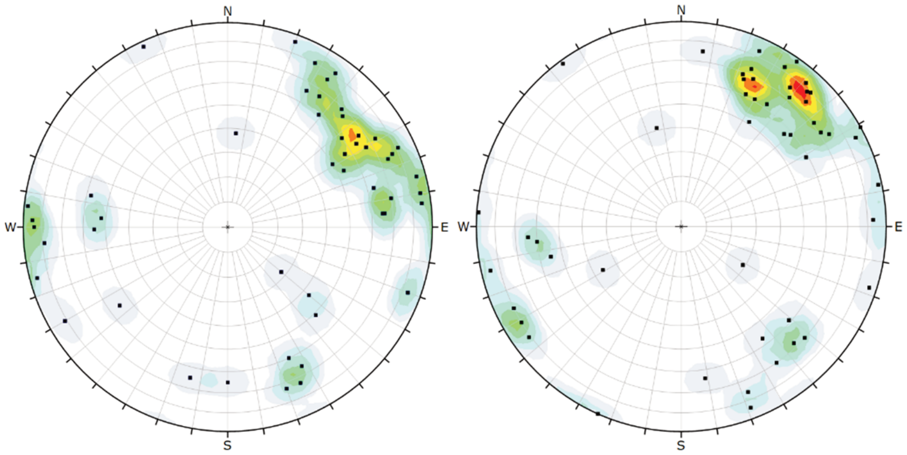
Table 5 Results of the Brewer Lake experiments (Gallant & Marshall 2016)

	Hand measurements	Stationary LiDAR	Biased 3DAM	Unbiased 3DAM
Number of poles	101	257	605	688
Joint orientations (dip/dip direction)				
Set 1	77/137	61/134	77/134	75/137
Set 2	89/060	83/056	89/234	89/057
Set 3	28/314	39/308	40/302	22/297
Angular difference with respect to hand measurements (deg)				
Set 1	–	16.2	2.9	2.0
Set 2	–	7.2	6.3	3.0
Set 3	–	11.5	13.7	9.3

While the data presented in Table 5 is similar to the results obtained from this study and reported in Table 4, it is clear that the data sets collected for this paper are limited and contain potential errors from interference. The correlation identified should not be considered definitive and more data should be collected and examined in future studies to further refine the comparison presented here. The identified suggested correlation is further observed visually in the stereonets presented below.

4.1.2.1 Site A stereonets

Data collected for Site A, including compass measurements which are suspected of interference from uncontrolled variables, is presented in Figure 5.

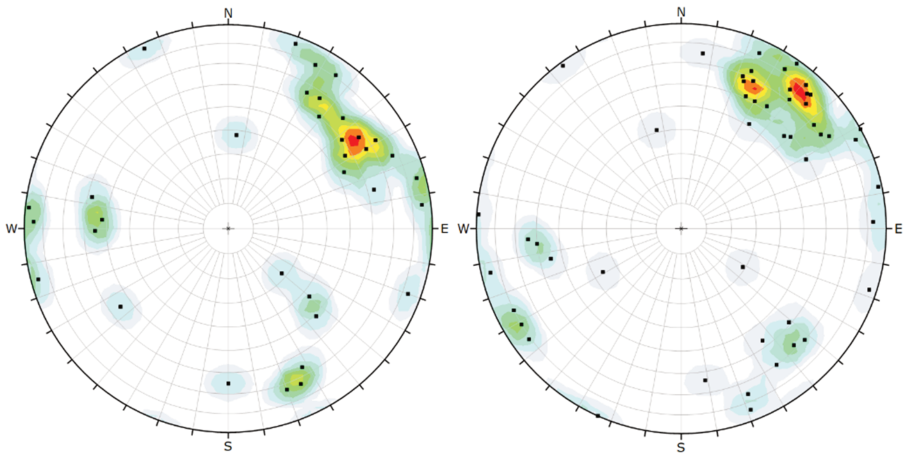


(a) (b)

Figure 5 Stereographic projection of (a) Compass and (b) Axis Mapper measurements for Site A

Site A measurements experienced some forms of interference during compass measurements as defined in Section 3.3.2.1, however, the data spread represented stereographically suggests that the Axis Mapper was typically recording dip direction orientations between -10° and -20° when compared to a compass.

The stereographic projection of mapping data trends well with numerical data presented in Table 3. When compass measurements suspected of being affected by interference are removed, the comparison improves, as shown in Figure 6.



(a) (b)

Figure 6 Stereographic projection of compass data after removal of measurements affected by interference for (a) Site A and (b) Axis Mapper measurements

The measurements from Site A do not align perfectly on a stereonet, however, the data concentrations suggest that there is a consistent slight variation of the dip direction for the major sets when measured using the two methods. Additional data collection of structures in which interference from uncontrolled variables is managed are necessary to further define the variation between the two methods.

4.1.2.2 Site B surface outcrop

Data collected at the Site B surface outcrop is presented in Figure 7 with both manual and Axis Mapper measurements highlighted.

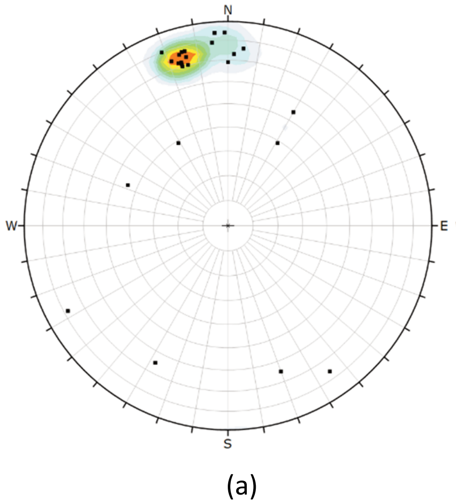


Figure 7 Stereographic projection of (a) Compass and (b) Axis Mapper measurements at Site B surface outcrop

No measurement interference was observed during compass measurements at the Site B surface outcrop, however, the Axis Mapper may have experienced measurement interference from sunlight, but it was not possible to observe the effect of this interference so the data precision remains unknown.

Similar to Site A, the data concentrations on the stereographic projection approximately align and suggest approximately a 10° dip direction difference exists for the main structure concentration near the 350° azimuth. Approximately half of the other unconcentrated data points vary, on average, by 10° in dip direction, suggesting a poor fit for those individual measurements. As with Site A, more data is needed to further refine the precision assessment comparing the Axis Mapper to a compass.

4.1.2.3 Site B underground

Data collected underground is presented in Figure 8 with both manual and Axis Mapper measurements highlighted.

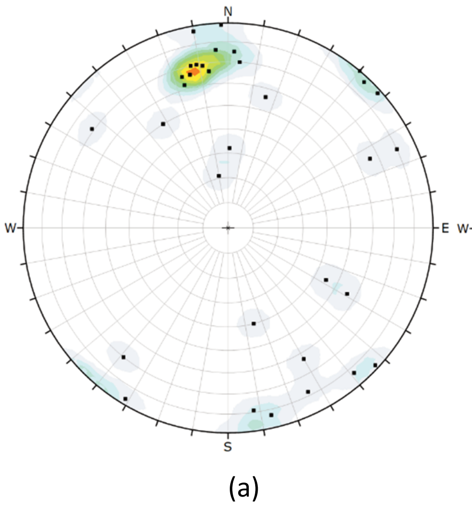


Figure 8 Stereographic projection of (a) Compass and (b) Axis Mapper measurements at Site B underground

The stereographic projection for Site B underground exhibits a good correlation between the Axis Mapper and the compass for the main structural concentrations, however, from the stereonets, it is clear that the individual structural measurements vary, on average, by 11°. The Site B underground comparison suggests that structural set correlation can be achieved between both methods even if individual structural measurements, are noted to vary.

As with Site A and the Site B outcrop data, further bulk data capture is needed to refine the correlation suggested by this case study. A greater amount of data captured over longer periods of time with mitigation of sources of interference will continue to refine these initial observations. It is currently unknown if measurement differences for individual structures are less variable when sources of interference are controlled.

4.2 Measurement speed

The data collection time was recorded for both methods at each of the three locations for the Canadian study. Table 6 shows the recorded times.

Table 6 Measurement speed comparison in minutes and seconds

Location	Axis Mapper capture time (mm:ss)	Compass capture time (mm:ss)	Number of structures measured
Site A	14:30	48:06	50
Site B outcrop	11:14	14:45	25
Site B underground	19:34	31:00	33

The Axis Mapper was consistently faster at measuring orientation in comparison to a compass. Some sources of interference, as discussed in Section 3.3.2.1, were encountered with both the Axis Mapper and the compass which caused measurement delays for both methods. The Axis Mapper encountered wet surfaces at the Site B underground location and the compass encountered obstructions and magnetic interference from ground control at Site A and Site B underground.

The data suggests that the Axis Mapper is faster at capturing orientation measurements by up to three times under ideal conditions for the Axis Mapper and sources of interference or obstruction exist for the compass. When both methods experience interference the Axis Mapper is approximately 1.5 times faster than a compass. The small data set has variability in capture speed as shown by a capture of 50 structures in 14 minutes and 30 seconds at Site A, while half the amount of structures were captured in 11 minutes and 14 seconds at the Site B outcrop. More data is needed to define a defensible capture speed difference between the Axis Mapper and a structural compass.

Average speed of data collected per structure for the Canadian study is 25 seconds for the Axis Mapper and 52 seconds for the compass, suggesting that, on average, when considering the limited data set, the Axis Mapper is approximately twice as fast as a compass for orientation measurement capture.

5 Conclusion

The Axis Mapper is a new technology for use in measuring structural orientation in underground environments. Two case studies were assessed to understand the precision and speed of the Axis Mapper compared to a structural compass.

Both case studies suggest that the comparative precision of the Axis Mapper measurements may vary from as little as 3° dip and 5° dip direction, up to 23° dip and 30° dip direction, for a limited number of individual measurements. Data concentrations of structural data were noted to vary up to 11° dip direction and 4° dip.

The data also suggests that, for measurement of structural orientation, the Axis Mapper is between 1.5 and 3 times as fast compared to as using a compass. Although, due to the limited data used for the speed assessment, the results were highly variable and need to be further refined.

These conclusions are based upon limited data in areas with identified sources of measurement interference and should not be considered definitive. Additional data from other underground sites was unable to be collected due to travel and access restrictions imposed during the COVID-19 pandemic.

Ultimately, due to factors outside of the authors' control, the data collected for this paper should remain suspect and suggested correlations should be treated as preliminary, requiring additional verification in controlled environments. The data from this paper will be a stepping-stone to a more complete comparison between measurements collected by the Axis Mapper tool and a structural compass.

Further data is required to support or reject the correlations suggested by these case studies. As additional opportunities for site access are identified in the coming year, a controlled underground location should be identified for mass data capture to definitively understand the measurement differences between the Axis Mapper and a structural compass.

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